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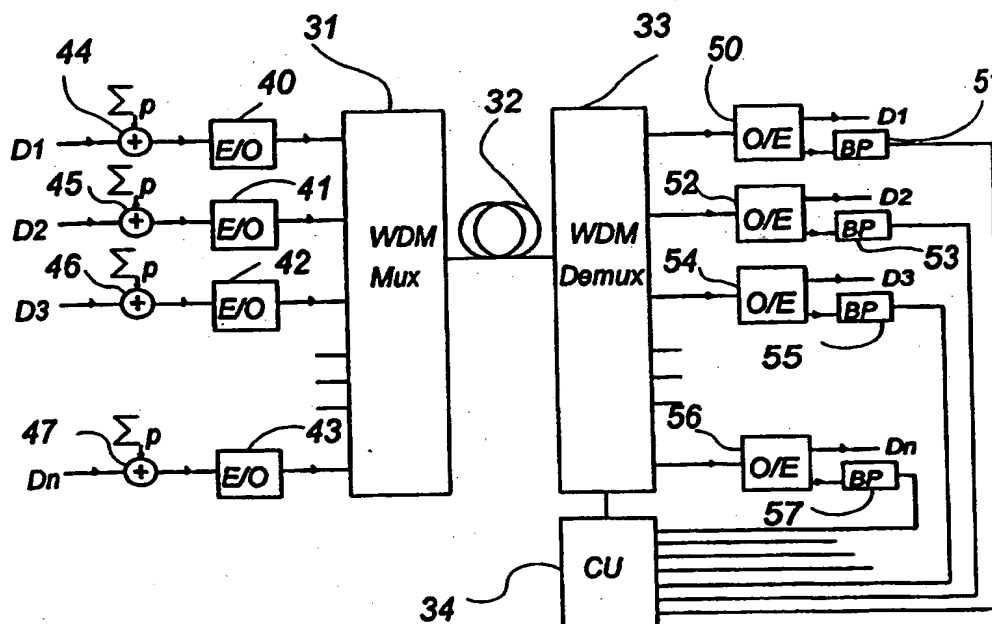
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(54) Title: A METHOD AND A SYSTEM FOR CODING WDM SIGNALS



(57) Abstract

The invention relates to a method for the transmission of optical data signals in a WDM system comprising two or more wavelength multiplexed data signals, wherein each multiplexed data signal is transmitted optically at mutually different wavelengths, and wherein each data signal (D_1 - D_n) at the transmitter side is AM modulated with at least one LF pilot signal (f_1, f_2, \dots, f_n) which is specific for the data signal concerned. According to a particularly advantageous embodiment of the invention, each individual data channels is coded with its own unique combination of pilot signals. The invention enables quick detection of a very large number of specifically marked WDM channels.

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A method and a system for coding WDM signals

Field of the art

5 The invention relates to a method as defined in the introductory portion of claim 1 for the transmission of optical data signals in a WDM system comprising two or more wavelength multiplexed data signals, wherein the multiplexed data signals are transmitted optically at mutually
10 different wavelengths.

The invention moreover relates to a system as defined in the introductory portion of claim 5 for the transmission of WDM data signals, said system comprising at least one
15 WDM multiplexer and at least one WDM demultiplexer connected thereto via an optical signal path, the optical inputs of the WDM multiplexer being fed by E/O converters, such as lasers, which each generate a channel-specific wavelength, said E/O converters being modulated by
20 data signals.

Finally, the invention also relates to an AM modulation unit for a WDM system as defined in claim 9.

25 In connection with the ever increasing use of optical transmission fibres for data communication/telecommunication there is an ever greater need for the development of an increased transmission capacity. This development means that it becomes increasingly difficult
30 for the existing cable connections to offer the capacity which the market can consume. The development has not become less pronounced with the growing popularity and use of e.g. the internet. Another example is the increased transmission need in video transfer via data
35 signals on the telecommunications network.

A consequence of this development is of course that the transmission capacity in the existing cable networks has to be extended and/or made more effective. As extension of the optical cable network is an extremely expensive operation, it is attempted to optimize the use of the existing cable network to the greatest extent possible without laying further cables, when this can be avoided. This may e.g. be done by modifying or replacing the transmission hardware used. In spite of the implementation costs involved by this, the costs will only be a fraction of the costs which supplementary laying of new cable connections would involve.

Two concrete examples of this modification are known from TDM, Time Division Multiplexing, and WDM, Wavelength Division Multiplexing, whereby the data capacity may be increased considerably. The most important difference between the two types of transmission of TDM may be considered as a purely sequential transmission protocol, where a specific range of the data sequence is allocated to each transmission channel, while WDM may rather be regarded as a parallel and mutually independent transmission of several optical channels in the same fibre, a specific wavelength being allocated to each channel.

By nature, a drawback of TDM is that it basically serves to increase the data channels at disposal, but does not increase the overall transmission capacity without increased transmission rate. WDM, however, provides both an increase in the data channels at disposal and a corresponding increase in the transmission capacity. In practice, the transmission wavelengths used will be located within a relatively small optical window with small wavelength intervals, which together are within the operational range of the optical amplifiers. Thus, it is abundantly clear that the data capacity of the overall

transmission system is increased very strongly for each added WDM channel.

5 The number of these channels thus increases greatly, and the 4-16 channels used at present are expected to be extended currently in the years to come in step with the development of the hardware components necessary for the purpose. This particularly applies to the necessary optical filters and laser components.

10

However, a problem involved by the use of WDM is that the individual channels at the receiver side are to be branched again to separate signals after transmission. This problem is particularly pronounced at the receiver
15 side where the individual demultiplexed signals, although they might be found, cannot readily be identified unambiguously under all conditions, as they usually do not have channel identification in the data frame for WDM channel identification. Further, it is difficult to decide where
20 a channel has dropped out or is just passive for a period of time.

The invention

25 When each data signal (D_1 - D_n) at the transmitter side is AM modulated with at least one LF pilot signal (f_1 , f_2 ,... f_n) which is specific for the data signal concerned, it is possible to perform a simple unambiguous on/off detection of the WDM channels at the receiver side.

30

A further advantage of the invention is that the overall transmission system may be varied dynamically, so that given transmission channels do not necessarily have to be located to a specific filter in the multiplexer. A possible
35 change in wavelengths in the WDM channels at the transmitter side will thus only cause the tuneable fil-

ters at the receiver side to tune into the new or changed WDM channels automatically or under control.

5 When the data signals (D1-Dn) are AM modulated with the pilot signal (Ps-Pn) before the E/O conversion, an advantageous embodiment of the invention is achieved, as the electrical modulation of the data signal may be obtained in a simple manner by modulation with electrical pilot signal generators.

10

When each data signal is AM modulated with a combination of at least two LF pilot tone signals, a particularly advantageous embodiment of the invention is achieved, as each data signal may be coded unambiguously in such a manner that the total number of employed pilot signals of different frequency is reduced. An essential advantage of this coding is thus that the multiplexed optical WDM signal has a limited number of different pilot signal components. This circumstance becomes extremely pronounced with an increase in the channels of the WDM system, making it necessary to extend the bandwidth of the WDM signal at disposal for the desired LF components. As pilot signals should be kept below a limit frequency of about 50 kHz to the greatest possible extent in order not to turn into noise in the LF components of the WDM signal, the present embodiment will thus allow marking of more optical WDM channels than would otherwise have been possible. It should be noted in this connection that the more closely spaced the individual pilot frequencies are, the more narrow-banded the filters must be at the receiver side. It should additionally be mentioned that the invention is also particularly advantageous in connection with the identification of the pilot signals at the receiver side, as the bandwidth of the filter to be used in order to filter the pilot signals must be relatively great. This means in turn that the time constant of the filters

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may be minimized, thereby allowing the detection response time to be minimized at the receiver side.

It will thus be appreciated that the advantages of the invention become more pronounced with a growing number of WDM channels.

When the LF pilot tone combination comprises $r+1$ mutually different pilot signals for a 2^r channel WDM system, in which all the frequencies of the pilot signals used are below 50 kHz, a particularly advantageous embodiment of the invention is achieved, as $n+1$ different pilot signals are sufficient for unambiguously modulating all the channels in a 2^r channel WDM system. It will likewise be appreciated that the invention is particularly advantageous with an increasing number of channels. For example, according to the invention, a 256 channel WDM system may be coded with just nine different pilot signals, all of which can be detected using relatively inexpensive electrical filters with a small time constant. Scanning in the demultiplexer over a given optical domain may thus be performed extremely quickly according to the invention.

It should moreover be noted that $r+1$ coding of the WDM channels ensures that all WDM channels are marked and can therefore be recognized positively.

When the demultiplexer is provided with tuneable BP filters, which each are controlled by a control unit in response to the emitted pilot tone content on the outputs of the O/E converters, so that each tuneable filter is tuned into a well-defined and identified WDM channel, a particularly effective control and monitoring of the individual WDM channels is achieved.

If some channels might have dropped out, either because of a technical error or because the system is e.g. in a low load period, the control unit can positively detect how many and specifically which channels are actually present on the output of the demultiplexer, and the control unit can record on the basis of this information how many and which channels are not present on the demultiplexer.

- 10 Accordingly, it will be possible to allow the tuneable filters in the demultiplexer to scan the fed light spectrum on the input of the demultiplexer under control of the control unit. This scanning is thus possible with a specific marking of each channel, as, otherwise, the control unit cannot record the WDM channel into which the filter has actually been tuned.

Drawing

- 20 The invention will be described below with reference to the drawing, in which

fig. 1 shows an example of a WDM system according to the invention,

- 25 fig. 2 shows an example of the spectral distribution of the pilot tones used according to the invention,

- fig. 3 shows an example of how WDM channels are distributed relative to wavelength,

fig. 4 shows an example of a preferred embodiment of the invention, and

- 35 fig. 5 schematically shows how a 16 channel WDM may be AM modulated by just five pilot tones.

Example

Fig. 1 shows an illustration of an embodiment of the invention.

The four channel WDM system shown comprises a WDM multiplexer 1 which is optically connected to a WDM demultiplexer 3 by means of an optical fibre 2.

The system comprises four summation units 14, 15, 16 and 17 which sum up four data signals D1, D2, D3 and D4 and a corresponding channel-specific pilot signal p1, p2, p3 and p4.

Subsequently, the amplitude modulated electrical signals are fed to the E/O converters 10, 11, 12 and 13, i.e. electrically modulated lasers, which are electrically connected to the summation units 14, 15, 16 and 17. Each laser is thus modulated with signals D1+p1, D2+p2, D3+p3 and D4+p4.

Each data channel D1, D2, D3 and D4 is modulated by the E/O converters at channel-specific wavelengths. The wavelength λ for each channel will typically be within a window of $1550 \text{ nm} \pm 10 \text{ nm}$ for standardized systems. A channel position may e.g. be ch1 = 1544 nm, ch2 = 1547 nm, ch3 = 1553 nm, ch4 = 1556 nm. The pilot signal frequency may e.g. be selected to be 10 kHz, 12.5 kHz and 17.5 kHz for each channel.

The multiplexed pilot signal modulated signals are then transmitted to the WDM demultiplexer 3 via the optical transmission path 2 in which the signal is split into four separate optical signals and fed to four O/E converters 20, 22, 24 and 26 by means of tuneable optical BP

filters not shown tuneable in the demultiplexer 3. The O/E converters 20, 22, 24 and 26 will typically be formed by photodiodes.

5 The electrical output from the O/E converters 20, 22, 24 and 26 is subsequently split into an HF and an LF component by means of an electrical, tuneable LP/BP filter arrangement 21, 23, 25 and 27 arranged for each channel. The LF component, which contains the channel-specific
10 modulation signal on the data signal, is subsequently fed back electrically to a control unit 4, CU, for each channel, said control unit controlling the tuneable filters in the demultiplexer 3 on the basis of the information achieved. The HF components remaining after the LP
15 filtering then constitute the original data signals D1, D2, D3 and D4.

In practice, the splitting of the LF and HF components may take place in several ways known per se within the
20 scope of the invention.

The HF signals wavelength filtered in the demultiplexer 3, i.e. D1, D2, D3 and D4 each having a channel-specific identifier p1, p2, p3, p4 modulated thereon, can thus be
25 recognized unambiguously by means of the identifier p1, p2, p3 and p4, and the tuneable filters in the demultiplexer 3 can therefore scan the added light spectrum on the input of the demultiplexer under control of the control unit 4. This scanning is thus just possible with a
30 specific marking of each channel, as the control unit cannot record either into which WDM channel the filter has actually been tuned.

If a tuneable filter has thus been tuned into an already
35 found WDM channel, the control unit 4 will record this coincidence and ensure that the filter continues to scan

until a channel not previously "locked" has been found. Further, the control unit 4 will be able to record when all the searched channels have been found, and then the scanning is interrupted.

5 Conversely, the coding technique according to the invention ensures that the output of the demultiplexer, or more specifically the output of the O/E converters has full information on which channels are present and on
10 which output D1, D2, D3, D4 these are placed.

It will be appreciated that D1, D2, D3 and D4 will not necessarily or do not have to emerge from the O/E converters 20, 22, 24 and 26 in the well-arranged order
15 which is outlined in the figure. If a concrete output layout should be desired according to the invention, it is possible according to the invention to adapt the control unit 4 for this purpose.

20 A distinct advantage of marking each wavelength with an LF signal is that each signal may be identified unambiguously using relatively inexpensive and non-bulky LF filters.

25 Finally, it should be noted that the example shown is monodirectional. It will be appreciated, however, that the invention may also be implemented in a bidirectional WDM system.

30 Fig. 2 shows an illustration of how the components for the coding of a data channel may be constructed.

For one thing, LF components are used, which should typically be selected to be below an upper limit frequency of
35 50 kHz, thereby ensuring that the pilot signals do not

interfere with the HF signal and thereby impair the transmission quality.

The example shown uses five different pilot signals Ps1, Ps2, Ps3, Ps4 and Ps5, as the signals shown may be used for complete multi pilot signal coding of a sixteen channel WDM system. The coding technique used will be described more fully with reference to fig. 5. It will be appreciated that more or fewer mutually different pilot signals may be used depending on the coding technique and the number of WDM channels.

Ps1, Ps2, Ps3, Ps4 and Ps5 may e.g. be selected to be 10 kHz, 12.5 kHz, 15 kHz, 17.5 kHz and 20 kHz, respectively.

15

If the pilot signal laying was to correspond to the example shown in fig. 1, the selected pilot signals would e.g. be Ps1, Ps2, Ps3 and Ps4.

It should be stressed that the figure just serves to illustrate the invention, which applies e.g. to the size of amplitude ratios. It will moreover be appreciated that the illustrated frequency intervals are just to serve to illustrate the mutual spacing between pilot signals and the frequency content of the data signal, respectively.

25

It will be seen from fig. 3 how the transmission channels may be distributed over the wavelengths λ_1 , λ_2 , λ_3 , λ_4 and up to λ_n . In practice, all the channels will be distributed over a window of $1550 \text{ nm} \pm 10 \text{ nm}$. In systems using a relatively large number of WDM transmission channels, the wavelength intervals are thus very small.

30

Fig. 4 shows an additional and preferred embodiment of the invention in which a plurality of pilot channels are coded on the data channel.

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As appears from fig. 2, the number of the necessary pilot tones according to fig. 1 will quickly become very large corresponding to the current number of channels. This should be seen in relation to the circumstance that the pilot signals should be below 50 kHz in order not to interfere with the data traffic in the WDM channel.

Such a problem will be eliminated in practice in fig. 4, since, according to this embodiment, each channel is coded with a combination of pilot signals Σp , which are subsequently split and identified unambiguously as a channel marking at the receiver side.

The shown example comprises n-channel WDM data signals which each are modulated in the electrical domain with a combination of pilot signals Σp . This combination should be regarded as a purely binary coding of each data signal by means of LF pilot signals.

The system thus includes n summation units 44, 45, 46 and 47 which sum up n data signals D_1 - D_n and a corresponding channel-specific pilot signal of combinations of P_1 - P_i , where "i" corresponds to the number of mutually different LF pilot signals.

The actual coding of the data signal will be described more fully with reference to fig. 5.

Subsequently, the summed electrical signals are fed to E/O converters 40, 41, 42 and 43, i.e. electrically modulated lasers, which are electrically connected to the summation units 44, 45, 46 and 47.

The wavelength λ for each channel will typically be within a window of 1550 nm \pm 10 nm in standardized systems.

5 The multiplexed pilot signal modulated signals are then transmitted to the WDM demultiplexer 33 via the optical transmission path 32, in which the signal is split to n separate optical signals and is fed to n O/E converters 50, 52, 54 and 56 by means of tuneable optical BP filters
10 not shown in the demultiplexer 33. The O/E converters 50, 52, 54 and 56 will typically be formed by photodiodes.

The electrical output from the O/E converters 50, 52, 54 and 56 is subsequently split into an HF component and an
15 LF component by means of an electrical, tuneable LP/BP filter arrangement 51, 53, 55 and 57 provided for each channel. The LF component containing the channel-specific modulation signal on the data signal is then fed back electrically for each channel to a control unit 4, CU,
20 which controls the tuneable filters in the demultiplexer 3 on the basis of the information achieved. The HF components remaining after the LP filtering then constitute the original data signals D1-Dn.

25 The HF signals BP filtered in the demultiplexer 33, i.e. D1-Dn each having a channel-specific identifier p1, p2, p3, ... p_i modulated thereon, can thus be recognized unambiguously by means of the identifier formed by the pilot signals, and the tuneable filters in the demulti-
30 plexer 33 can therefore scan the added light spectrum on the input of the demultiplexer under control of the control unit 34. This scanning is thus only possible with a specific marking of each channel, as, otherwise, the control unit will not be able to record into which WDM chan-
35 nel the filter has actually been tuned. Thus, the control unit 34 will ensure with simple control algorithms that

the tuneable filters in the demultiplexer 33 track all the various channels which may be found on the input of the multiplexer, i.e. up to n channels.

- 5 If some channels might have dropped out, either because of a technical error or because the system is e.g. in a low load period, the control unit can positively detect how many and specifically which channels are actually present on the output of the demultiplexer 33, and, on
10 the basis of this information, the control unit 34 can also record how many and which channels are not present on the demultiplexer.

Finally, it should be mentioned that the invention is not
15 restricted to monodirectional WDM signals.

Fig. 5 shows a table of an example of a coding of a 16-channel WDM system.

- 20 The example shown uses five pilot tones with the frequencies f_1 , f_2 , f_3 , f_4 and f_r which together may be modulated on the individual data channels at the transmitter side so that these may subsequently be found and recognized at the receiver side.

P A T E N T C L A I M S

1. A method for the transmission of optical data signals in a WDM system comprising two or more wavelength multiplexed data signals, wherein the multiplexed data signals are transmitted optically at mutually different wavelengths,

c h a r a c t e r i z e d i n

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that each data signal (D1-Dn) at the transmitter side is AM modulated with at least one LF pilot signal (f1, f2, ... fn) which is specific for the data signal concerned.

15 2. A method according to claim 1, c h a r a c t e r - i z e d i n that the data signals (D1-Dn) are AM modulated with the pilot signal (Ps-Pn) before the E/O conversion.

20 3. A method according to claim 1 or 2, c h a r a c - t e r i z e d i n that each data signal is AM modulated with a combination of at least two LF pilot tone signals.

25 4. A method according to claims 1-3, c h a r a c t e r - i z e d i n that the LF pilot tone combination comprises r+1 mutually different pilot signals for a 2^r -channel WDM system, in which all the frequencies of the pilot signals used are below 50 kHz.

30 5. A system for the transmission of WDM data signals, comprising

a WDM multiplexer (31) and a WDM demultiplexer (33) connected thereto via an optical signal path (32), the optical inputs of the WDM multiplexer (31) being fed by E/O converters (10, 11, 12, 13; 40, 41, 42, 43), such as la-

35

sers, which each generate a channel-specific wavelength ($\lambda_1, \lambda_2, \lambda_3, \dots \lambda_n$), said E/O converters being modulated by data signals ($D_1, D_2, D_3, \dots D_n$),

5 c h a r a c t e r i z e d i n t h a t

the system is additionally adapted to AM modulate each data signal ($D_1, D_2, D_3, \dots D_n$) with at least one LF pilot signal ($Ps_1, Ps_2, Ps_3, \dots Ps_n$) before these are fed
10 to the E/O converters (10, 11, 12, 13; 40, 41, 42, 43), said pilot signals having mutually different frequencies.

6. A system according to claim 5, c h a r a c t e r -
i z e d i n t h a t the system is adapted to AM modulate
15 each data signal ($D_1, D_2, D_3, \dots D_n$) with a combination of pilot signals specifically selected for the data signal.

7. A system according to claim 5 or 6, c h a r a c -
20 t e r i z e d i n t h a t the demultiplexed optical outputs of the demultiplexer (3; 33) are connected to O/E converters (20, 22, 24, 26; 50, 52, 54, 56), such as photodiodes, said O/E converters being adapted to split the fed signals into an electrical HF data signal (D_1-D_n) and
25 an electrical LF pilot tone signal, said split LF pilot tone signal being fed to a detection arrangement which is adapted to detect which pilot signals ($Ps_1, Ps_2, Ps_3, \dots Ps_n$) or which combinations of pilot signals the LF signal contains.

30

8. A system according to claims 5-7, c h a r a c t e r -
i z e d i n t h a t the demultiplexer (3; 30) is provided with tuneable BP filters, which each are controlled by a control unit (4, 34) in response to the emitted pilot
35 tone content on the outputs of the O/E converters (20,

22, 24, 26; 50, 52, 54, 56) so that each tuneable filter is tuned into a well-defined and identified WDM channel.

9. An AM modulation unit for a WDM system comprising at least two pilot signal generators which each are adapted to generate mutually different frequencies so that the modulation unit generates a given output combination of pilot signals.
- 10 10. An AM modulation unit for a WDM system according to claim 9, characterized in that the output combination of pilot signals may be controlled by means of control signals fed to the modulation unit.
- 15 11. An AM modulation unit for a WDM system according to claim 9 or 10, characterized in that the output combination of pilot signals is generated by permanently wired pilot signal generators.

1/2

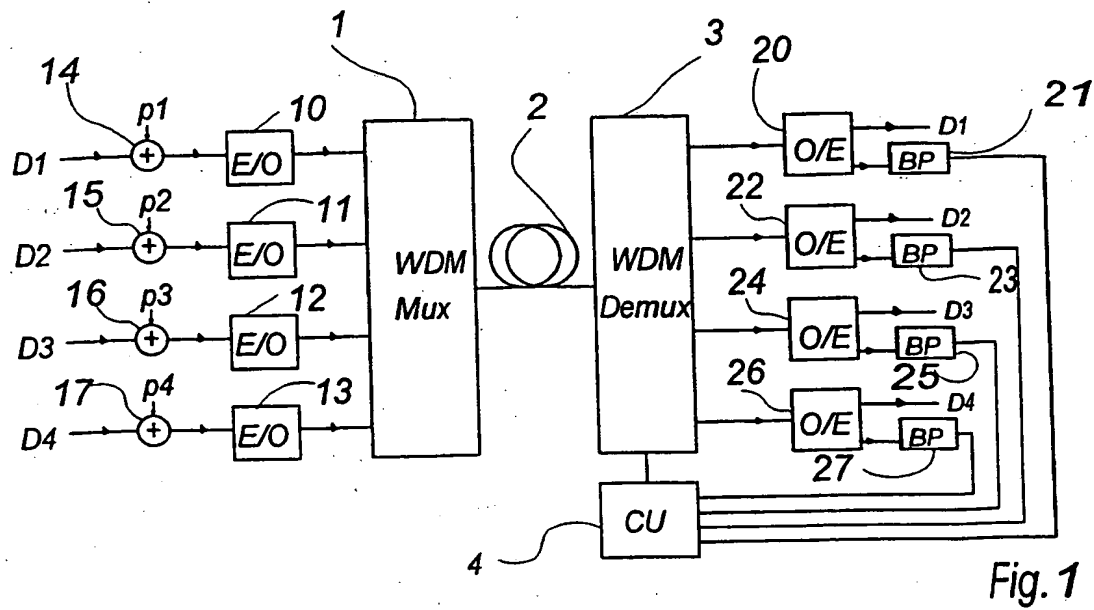


Fig. 1

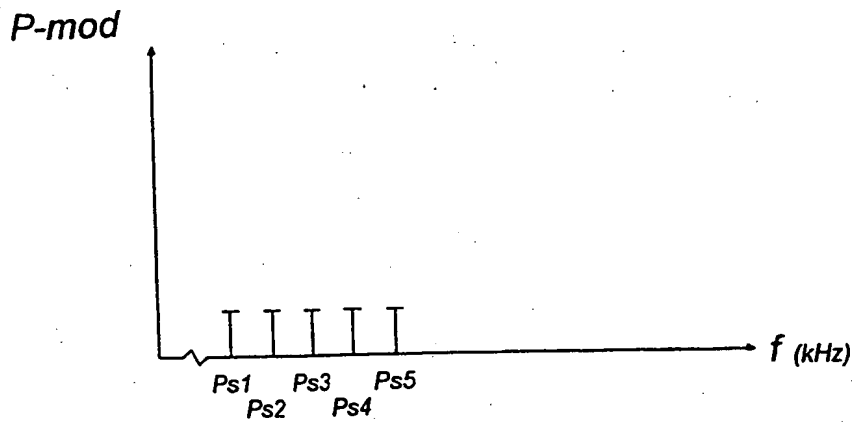


Fig. 2

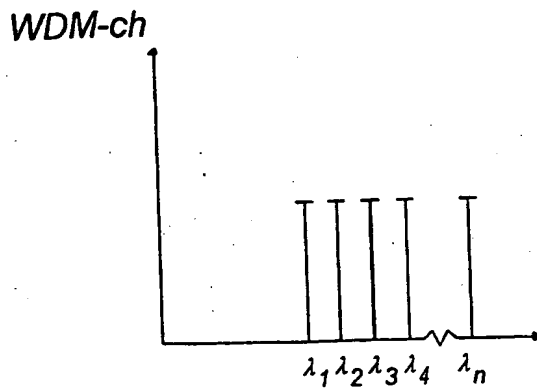


Fig. 3

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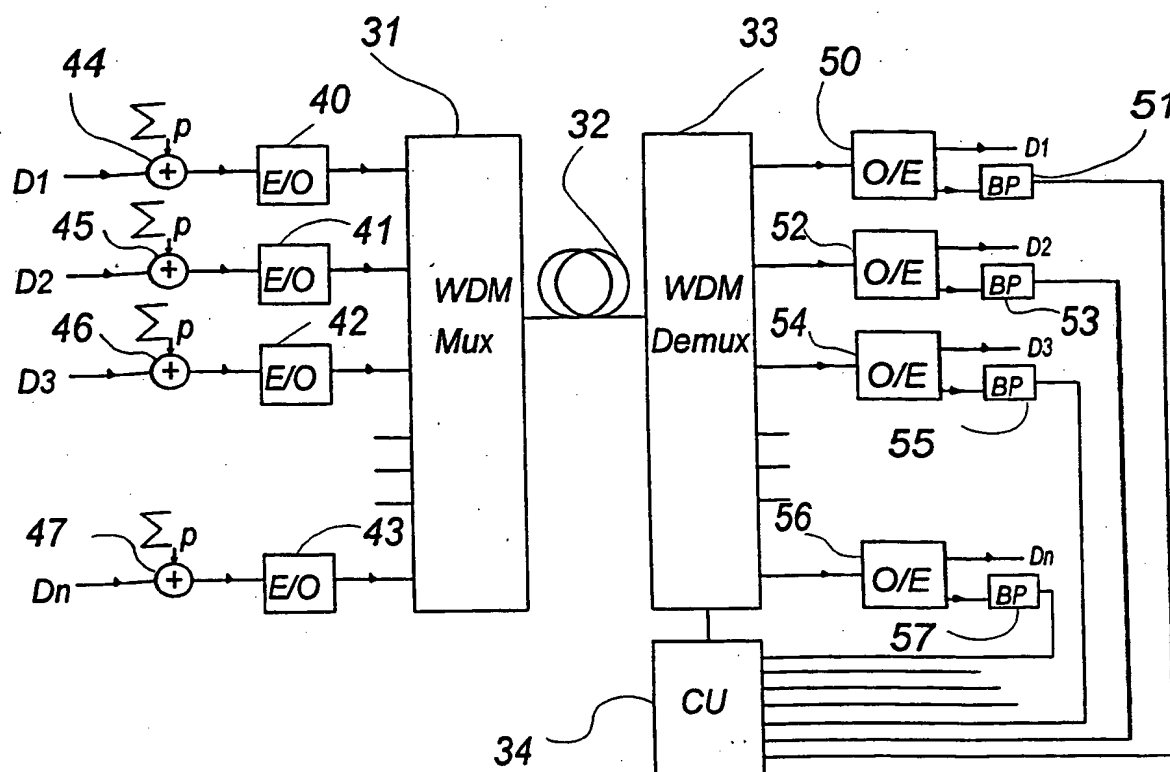


Fig. 4

ch	f_1	f_2	f_3	f_4	f_r
1	-	-	-	-	1
2	-	-	-	1	1
3	-	-	1	-	1
4	-	-	1	1	1
5	-	1	-	-	1
6	-	1	-	1	1
7	-	1	1	-	1
8	-	1	1	1	1
9	1	-	-	-	1
10	1	-	-	1	1
11	1	-	1	-	1
12	1	-	1	1	1
13	1	1	-	-	1
14	1	1	-	1	1
15	1	1	1	-	1
16	1	1	1	1	1

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK 98/00565

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04B 10/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

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IPC6: H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5212579 A (DAVID R. HUBER ET AL), 18 May 1993 (18.05.93), column 6, line 63 - column 7, line 29, figure 7 --	1-3,5,7-11
A	US 5371625 A (BERTHOLD WEDDING ET AL), 6 December 1994 (06.12.94), column 2, line 19 - column 4, line 56 -- -----	1-11



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INTERNATIONAL SEARCH REPORT

Information on patent family members

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